Memorandum

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DATE: January 14, 2013 NHC PROJECT: 200051

TO: Erik Peters, P.E.

COMPANY/AGENCY: King County WLRD

FROM: Alex Anderson, P.E., Vaughn Collins, P.E.

SUBJECT: Reddington Levee Setback Project 90% Design Submittal: Hydraulic Modeling

Northwest Hydraulic Consultants (NHC) has conducted HEC-RAS modeling to evaluate the hydraulic impacts of the proposed Reddington levee setback project. Phase 1 of the project involves replacing the existing levee with a setback levee between River Miles (RM) 28.2 and 29.5, as well as adding a series of buried rock barbs. A future Phase 2 would potentially involve extending the setback levee downstream to S 277th St (RM 27.6). Only Phase 1 is evaluated in this memorandum.

This memorandum describes model development, discusses the changes to water surface elevations under 100-year flood conditions as a result of the project, and evaluates levee risk and reliability with the recently issued changes to flood frequency estimates. Other uses of the model include supporting the geomorphologic and scour analyses, rock barb design, and revetment armor sizing. Documentation of these uses is provided in the accompanying 30% design memorandums by NHC.

Hydrology

Design of the project has used a 100-year flood flow estimate from the most recent Flood Insurance Study (NHC, 2008). After completion of this study, the Corps of Engineers determined that Howard Hanson dam could only regulate flows to a 140-year flood. During evaluation of the dam safety issues at the dam, numerous simulations of various reservoir inflow and regulation scenarios were conducted. In the absence of more detailed analysis, one of these scenarios was adopted as the best available estimate of the 500-year flood and used for design of much of the lower Green levee system upgrades to date. This scenario has a peak flow at the Auburn gage of 14,900 cfs. In November 2012 the Corps of Engineers released a report with newly developed flood frequency estimates, including uncertainty bands, for the Green River (Corps, 2012). The new estimate of the 500-yr flow is 18,800 cfs. King County has decided that the levee design profile, based on the older 500-yr flow estimate, will not be changed. Levee risk and reliability under the new hydrology is evaluated at the end of this memorandum.

HEC-RAS Model Development

NHC previously performed a zero-rise analysis during the feasibility stage of this project using the HEC-RAS model created for the King County Appeal to the FEMA Preliminary FIS as its basis. A description of this model may be found in NHC (2008). This model contains cross-section spacing of approximately

700-1000 ft in the project area, and the resulting analysis found a small rise created by the project at one location (NHC, 2011).

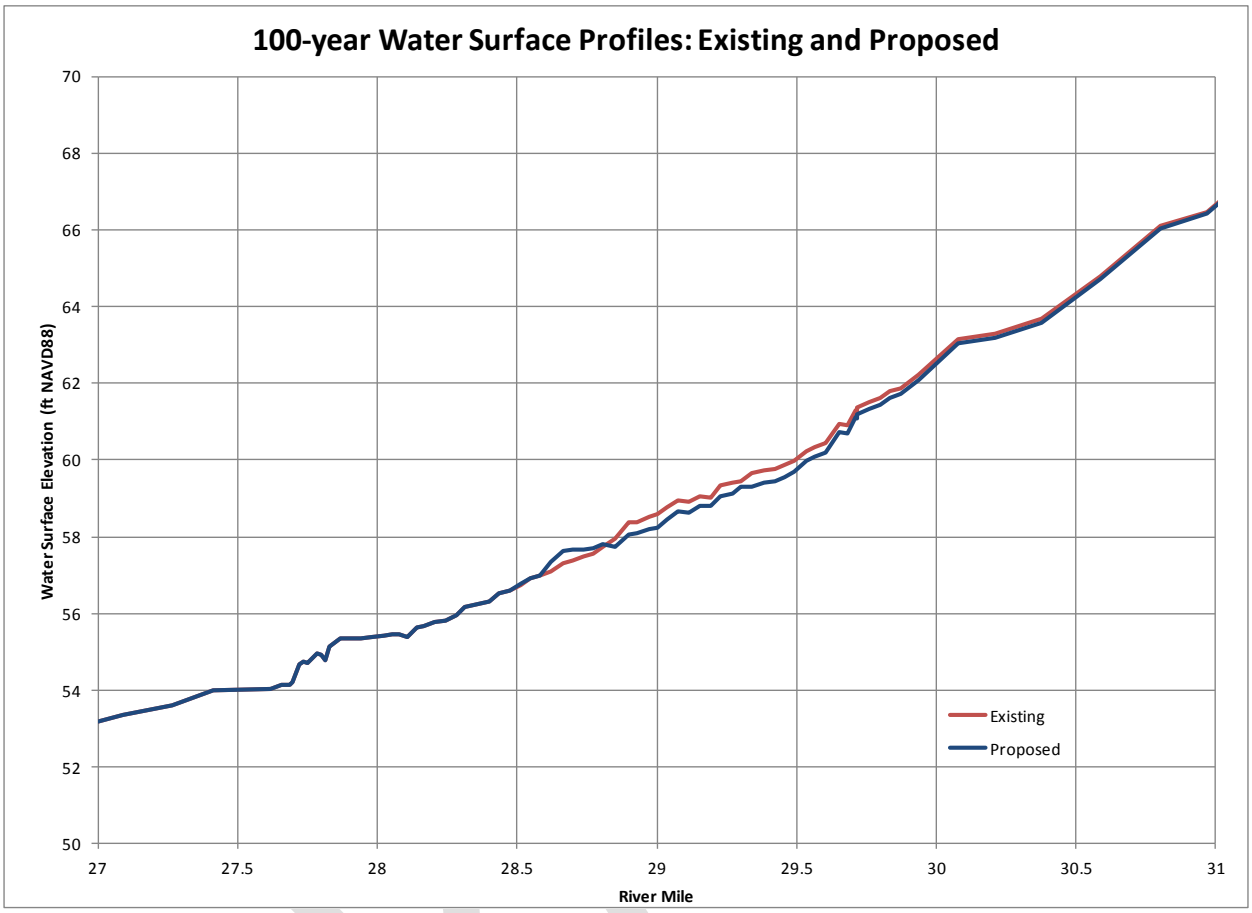
For the present analysis, a series of modifications and refinements were made to the hydraulic model in the project reach to allow more detailed evaluation of project impacts and design parameters. No changes were made to the King County Appeal model flood flows or geometry up or downstream of this reach. The model layout is shown in Figure 1. Key changes made were:

- New cross-sections spaced approximately every 200 ft were added between RM 27.62 and 29.87, the extents of the 2010 detailed bathymetric survey. Cross-section locations were adjusted where necessary to ensure that the bend scour holes and crossings were captured. Figure 4 shows the model cross-section layout within the project reach.
- The new existing condition cross-sections were based on the CAD topographic surface provided by Tetra Tech, which incorporates information from the March 2010 bathymetric survey of the project reach.
- Future condition cross-sections were also extracted from the with-project CAD surface for the proposed design. Ineffective areas and Manning n-values were adjusted as necessary to reflect the design condition.
- Manning n-values for the 200-ft spaced model cross-sections were derived from the King County Appeal model cross-sections, with minimal manual adjustments for forested areas along the banks.
- The Auburn Golf Course was made ineffective in the HEC-RAS model based on Flo2D modeling NHC conducted for the King County Appeal Study (NHC, 2008), which showed ponding on the golf course but essentially no conveyance.

Zero-Rise Analysis

Existing and proposed conditions under a 100-year flow of 12,500 cfs were simulated. The model results indicate a small rise within the project reach, similar to the finding of the feasibility study zero-rise analysis. This rise occurs despite the fact that the proposed project increases overall conveyance capacity throughout its length. The rise, which spans RM 28.512 to 28.809 and has a maximum value of 0.34 ft, occurs in the same area as the rise witnessed in the feasibility study. Figure 1 shows the water surface profiles during the 100-year flood for existing and proposed conditions, and shows this small rise centered around RM 28.6. Upstream, water surface elevations are lowered around 0.3 feet through the project reach and the reduction extends upstream several miles before tapering off (Figure 1, Table 1).

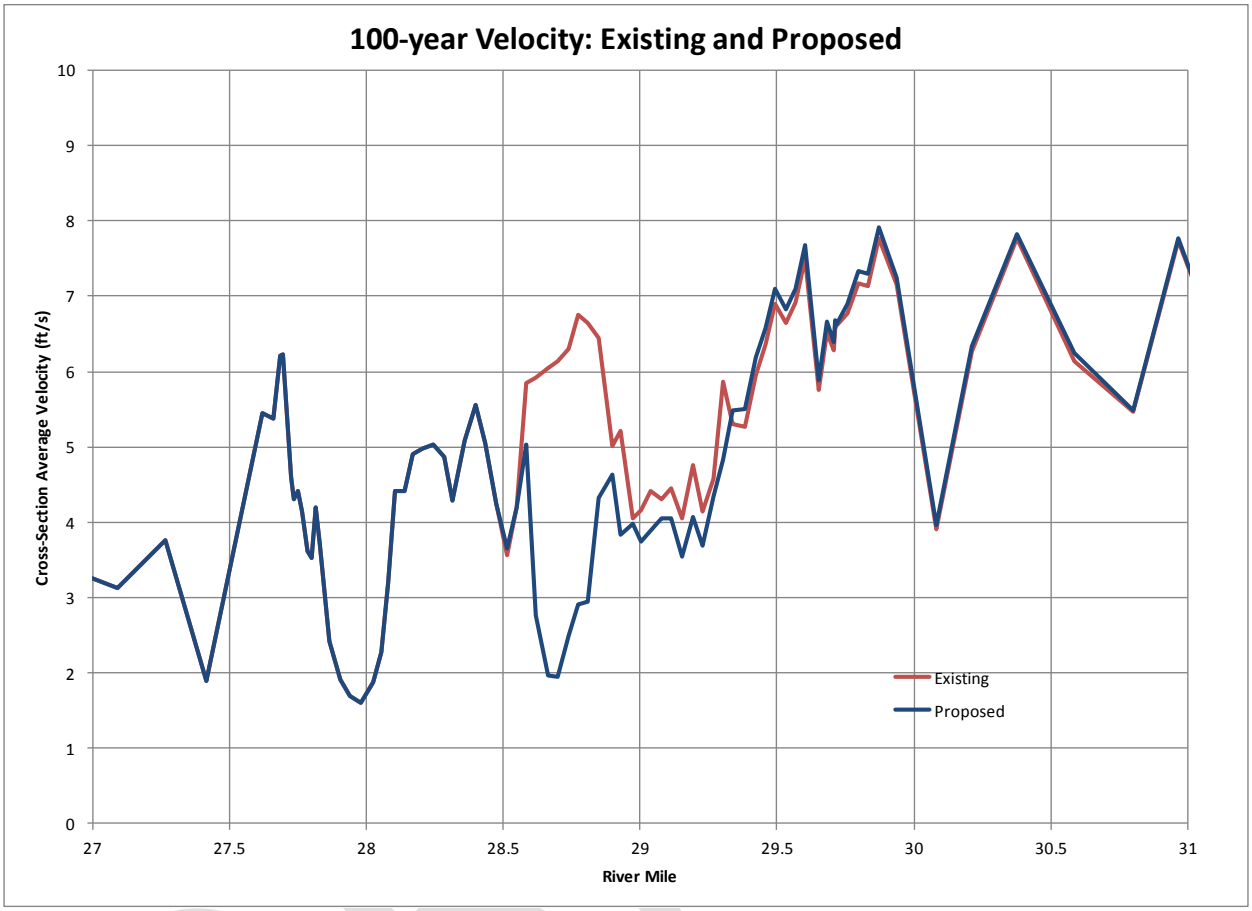
Figure 1: 100-year water surface profiles, existing (red) and proposed (blue).



The reason for this rise in water surface elevation is the large expansion of flow area in the immediate vicinity. The levee setback project, as currently envisioned, will allow flow to occur in the left overbank area that was cut off from the river as part of levee construction in the 1960's. This area has been isolated from the river and therefore any sediment sources since then, and so is at an un-naturally low elevation 5-6 feet below what would be expected for the floodplain at this location. With the addition of this enhanced overbank flow area, two things happen that affect the rise: the average cross-sectional velocity is reduced, and energy losses are reduced, resulting in a decrease in the energy grade line. The rise results when the decrease in velocity head ($v^2/2g$) is larger than the decrease in total energy (Table 1). At the cross-section that experiences the maximum rise (0.34 ft), the decrease in the energy grade line is 0.09 ft, but there is a 0.43 ft decrease in velocity head, resulting in the net rise of 0.34 feet. Figure 2 shows the large drop in velocity in this area that occurs with the proposed project. While a rise resulting from a larger flow area may seem counterintuitive, it is not all that unusual when cross-sections are enlarged and low velocity zones are activated.

It should be noted that near the edges of the floodplain, in low velocity areas and in any backwater zones, the energy grade equals the water surface elevation (as the velocity head is zero) and thus a reduction in energy grade indicates reduced backwater flooding and inundation. The energy grade is reduced throughout the project reach (Table 1).

Figure 2: Existing (red) and proposed (blue) 100-year velocity profiles. The rise results where the lines diverge, around RM 28.75.



In addition to the discussion above, it should also be noted that the potential water surface increases resulting from the levee setback project are contained within the levee system. The BFEs in the channel are more than a foot below the Green River Road that serves as the levee for the Auburn Golf Course, and will be four or more feet below the proposed Reddington setback levee.

500-year Design Flood Profile

The 500-year flood profile with 3.5 feet of freeboard is the design profile for the proposed setback levee. The design flow of 14,900 cfs was used and no changes were made to the revised model geometry. Results are given in Table 2.

Levee Risk and Reliability with New Corps Hydrology

The 5%, 50% and 95% estimates of floods from the 10 through 500-year events from the new Corps hydrology were simulated using the Lower Green River Extended Containment Flo2D model. The median 500-yr flow estimate of 18,800 cfs (Corps, 2012) was also simulated in the HEC-RAS model. Results indicate the levee does not overtop at this flow, although freeboard is reduced to around 1.2 feet in the HEC-RAS model. Flo2D results indicate freeboard varying from around 2.3 feet at the lower end of the project to 0.3 feet at the upper end.

Results from Flo2D modeling at three locations spanning the project were input into a HEC-FDA model using both stage-frequency and flow-frequency approaches and are shown in Table 1.

Table 1: Levee Risk and Reliability under Revised Corps Hydrology with Proposed Levee Design Profile

Method	Location	Annual Exceedance Probability of Overtopping(%)		Long-Term Probability of Overtopping (%)			Conditional Non-Exceedance Probability by Events (%)*					
		Median	Ex-pected	10 yrs	30 yrs	50 yrs	10% (10-yr)	4% (25-yr)	2% (50-yr)	1% (100-yr)	0.4% (250-yr)	0.2% (500-yr)
Stage - Frequency	RM 28.2	0.08	0.12	1.22	3.61	5.94	99.95	99.95	99.95	99.95	99.95	99.68
	RM 28.8	0.13	0.16	1.60	4.72	7.74	99.95	99.95	99.95	99.95	99.95	91.06
	RM 29.5	0.16	0.19	1.83	5.40	8.83	99.95	99.95	99.95	99.95	99.95	72.77
Flow - Frequency	RM 28.2	0.01	0.02	0.17	0.51	0.85	99.98	100.00	99.97	99.78	98.53	97.60
	RM 28.8	0.01	0.08	0.80	2.39	3.95	99.99	100.00	99.80	98.14	92.82	88.11
	RM 29.5	0.01	0.17	1.69	4.98	8.18	99.99	99.98	88.48	95.51	85.07	78.40

*The probability that the levee will not overtop under the given flood.

Reliability at the upper end of the levee is the lowest, consistent with the least freeboard under Flo2D results. If using HEC-RAS model results reliability will be approximately that shown for RM 28.8 for the entire length of proposed levee.

Inundation Analysis

Please refer to the "Reddington Setback Levee Design Approach and Fish Habitat Considerations REVIEW DRAFT" memorandum for a detailed frequency-inundation analysis of the project.

References

Army Corps of Engineers, Seattle District, 2012. *Assembly of Design Flood Hydrographs for the Green River Basin – Summary Report for Flood Plain Management Services Program*. September 2012.

Northwest Hydraulic Consultants, 2008. *Floodplain Mapping Study for Lower Green River*. Prepared for King County River and Floodplain Management, Water and Land Resources Division.

Northwest Hydraulic Consultants, 2011. *Reddington Levee Setback Project, Zero Rise Evaluation*. Memorandum to Tetra Tech, Inc.

Table 2: Tabular results, 100-year & 500-year flood simulations between SR18 and S. 277th St

	100-Year Flood						500-Year Flood (14,900 cfs)
	Existing		**Proposed**		**Difference**		
River Mile	Water Surface El.(ft)	Energy Grade El.(ft)	Water Surface El.(ft)	Energy Grade El.(ft)	Water Surface El.(ft)	Energy Grade El.(ft)	Water Surface El.(ft)
SR 18 Bridge							
33.249	78.35	79.31	78.35	79.31	0.00	0.00	79.03
33.042	76.78	77.79	76.78	77.79	0.00	0.00	77.26
32.832	75.18	75.90	75.18	75.90	0.00	0.00	75.71
32.678	71.91	74.05	71.91	74.05	0.00	0.00	72.75
32.527	72.14	72.20	72.13	72.19	-0.01	-0.01	73.30
32.426	71.56	71.86	71.56	71.86	0.00	0.00	72.82
32.363	71.28	71.72	71.27	71.71	-0.01	-0.01	72.46
32.329	71.05	71.63	71.04	71.63	-0.01	0.00	72.19
32.250	70.47	71.38	70.46	71.37	-0.01	-0.01	71.52
32.074	70.56	70.85	70.55	70.84	-0.01	-0.01	71.73
31.903	69.67	70.47	69.66	70.46	-0.01	-0.01	70.81
31.734	69.42	69.94	69.41	69.93	-0.01	-0.01	70.57
31.586	68.86	69.55	68.85	69.54	-0.01	-0.01	69.95
31.441	68.46	69.15	68.44	69.14	-0.02	-0.01	69.55
31.287	67.47	68.56	67.45	68.54	-0.02	-0.02	68.47
31.276	67.56	68.46	67.54	68.44	-0.02	-0.02	68.58
31.089	67.11	67.88	67.09	67.86	-0.02	-0.02	68.08
8th St NE Bridge							
31.072	67.10	67.80	67.08	67.78	-0.02	-0.02	68.06
30.967	66.46	67.42	66.43	67.40	-0.03	-0.02	67.43
30.804	66.09	66.57	66.05	66.54	-0.04	-0.03	67.18
30.588	64.78	65.67	64.72	65.62	-0.06	-0.05	65.97
30.377	63.67	64.68	63.59	64.61	-0.08	-0.07	64.76
30.210	63.28	63.90	63.18	63.81	-0.10	-0.09	64.43
30.080	63.14	63.51	63.04	63.41	-0.10	-0.10	64.34
29.939	62.21	63.11	62.08	62.99	-0.13	-0.12	63.28

	100-Year Flood						500-Year Flood (14,900 cfs)
	Existing		Proposed		Difference		
River Mile	Water Surface El.(ft)	Energy Grade El.(ft)	Water Surface El.(ft)	Energy Grade El.(ft)	Water Surface El.(ft)	Energy Grade El.(ft)	Water Surface El.(ft)
29.872	61.88	62.84	61.72	62.72	-0.16	-0.12	63.07
29.834	61.78	62.61	61.61	62.47	-0.17	-0.14	62.97
29.798	61.61	62.43	61.43	62.29	-0.18	-0.14	62.81
29.759	61.52	62.25	61.34	62.10	-0.18	-0.15	62.71
29.716	61.38	62.13	61.20	61.96	-0.18	-0.17	62.55
29.715	61.27	62.03	61.08	61.86	-0.19	-0.17	62.42
29.710	61.29	62.00	61.10	61.83	-0.19	-0.17	62.45
29.681	60.92	61.65	60.70	61.46	-0.22	-0.19	62.09
29.652	60.95	61.52	60.74	61.33	-0.21	-0.19	62.13
29.605	60.44	61.34	60.19	61.13	-0.25	-0.21	61.58
29.567	60.33	61.12	60.08	60.89	-0.25	-0.23	61.49
29.535	60.23	60.95	59.96	60.71	-0.27	-0.24	61.39
Begin Project							
29.494	59.97	60.74	59.68	60.49	-0.29	-0.25	61.13
29.456	59.87	60.53	59.56	60.26	-0.31	-0.27	61.06
29.422	59.77	60.37	59.45	60.09	-0.32	-0.28	60.97
29.383	59.74	60.21	59.41	59.91	-0.33	-0.30	60.95
29.339	59.64	60.11	59.31	59.79	-0.33	-0.32	60.87
29.301	59.45	60.01	59.29	59.67	-0.16	-0.34	60.70
29.270	59.39	59.93	59.13	59.58	-0.26	-0.35	60.63
29.229	59.35	59.80	59.06	59.47	-0.29	-0.33	60.60
29.192	59.02	59.69	58.80	59.36	-0.22	-0.33	60.27
29.153	59.06	59.52	58.81	59.22	-0.25	-0.30	60.32
29.114	58.91	59.42	58.63	59.12	-0.28	-0.30	60.14
29.077	58.96	59.29	58.66	58.99	-0.30	-0.30	60.27
29.039	58.78	59.21	58.46	58.91	-0.32	-0.30	60.05
29.001	58.59	59.13	58.25	58.81	-0.34	-0.32	59.81
28.972	58.52	59.06	58.18	58.74	-0.34	-0.32	59.73
28.928	58.37	58.93	58.09	58.59	-0.28	-0.34	59.55
28.898	58.39	58.81	58.06	58.49	-0.33	-0.32	59.57

	100-Year Flood						500-Year Flood (14,900 cfs)
	Existing		Proposed		Difference		
River Mile	Water Surface El.(ft)	Energy Grade El.(ft)	Water Surface El.(ft)	Energy Grade El.(ft)	Water Surface El.(ft)	Energy Grade El.(ft)	Water Surface El.(ft)
28.850	57.95	58.64	57.75	58.34	-0.20	-0.30	59.07
28.809	57.75	58.48	57.81	58.15	0.06	-0.33	58.86
28.774	57.55	58.34	57.69	58.06	0.14	-0.28	58.64
28.736	57.50	58.15	57.67	57.95	0.17	-0.20	58.59
28.700	57.39	58.01	57.67	57.86	0.28	-0.15	58.83
28.666	57.30	57.90	57.64	57.81	0.34	-0.09	58.76
28.620	57.10	57.74	57.33	57.71	0.23	-0.03	58.49
28.583	56.97	57.60	56.99	57.59	0.02	-0.01	58.04
28.547	56.90	57.43	56.90	57.43	0.00	0.00	58.00
28.512	56.75	57.30	56.77	57.30	0.02	0.00	57.87
28.475	56.58	57.15	56.58	57.15	0.00	0.00	57.73
28.433	56.51	56.96	56.51	56.96	0.00	0.00	57.62
28.399	56.30	56.84	56.30	56.84	0.00	0.00	57.37
28.357	56.23	56.68	56.23	56.68	0.00	0.00	57.30
28.314	56.17	56.53	56.17	56.53	0.00	0.00	57.26
28.282	55.97	56.43	55.97	56.43	0.00	0.00	57.03
28.244	55.82	56.31	55.82	56.31	0.00	0.00	56.88
28.206	55.76	56.18	55.76	56.18	0.00	0.00	56.81
End Project							
28.168	55.67	56.07	55.67	56.07	0.00	0.00	56.71
28.139	55.63	55.98	55.63	55.98	0.00	0.00	56.67
28.105	55.38	55.88	55.38	55.88	0.00	0.00	56.40
28.078	55.46	55.76	55.46	55.76	0.00	0.00	56.51
28.054	55.45	55.70	55.45	55.70	0.00	0.00	56.52
28.023	55.43	55.65	55.43	55.65	0.00	0.00	56.51
27.979	55.39	55.58	55.39	55.58	0.00	0.00	56.46
27.941	55.34	55.53	55.34	55.53	0.00	0.00	56.40
27.903	55.33	55.47	55.33	55.47	0.00	0.00	56.40
27.865	55.33	55.42	55.33	55.42	0.00	0.00	56.39
27.830	55.12	55.37	55.12	55.37	0.00	0.00	56.16

	100-Year Flood						500-Year Flood (14,900 cfs)
	Existing		**Proposed**		**Difference**		
River Mile	Water Surface El.(ft)	Energy Grade El.(ft)	Water Surface El.(ft)	Energy Grade El.(ft)	Water Surface El.(ft)	Energy Grade El.(ft)	Water Surface El.(ft)
27.812	54.79	55.31	54.79	55.31	0.00	0.00	55.85
27.800	54.92	55.23	54.92	55.23	0.00	0.00	55.96
27.783	54.94	55.18	54.94	55.18	0.00	0.00	55.99
27.764	54.81	55.14	54.81	55.14	0.00	0.00	55.83
27.751	54.72	55.11	54.72	55.11	0.00	0.00	55.74
27.733	54.73	55.06	54.73	55.06	0.00	0.00	55.75
27.722	54.67	55.04	54.67	55.04	0.00	0.00	55.68
27.696	54.22	54.94	54.22	54.94	0.00	0.00	55.17
27.686	54.15	54.89	54.15	54.89	0.00	0.00	55.09
27.657	54.15	54.70	54.15	54.70	0.00	0.00	55.10
27.620	54.02	54.55	54.02	54.55	0.00	0.00	54.97
S. 277th St							

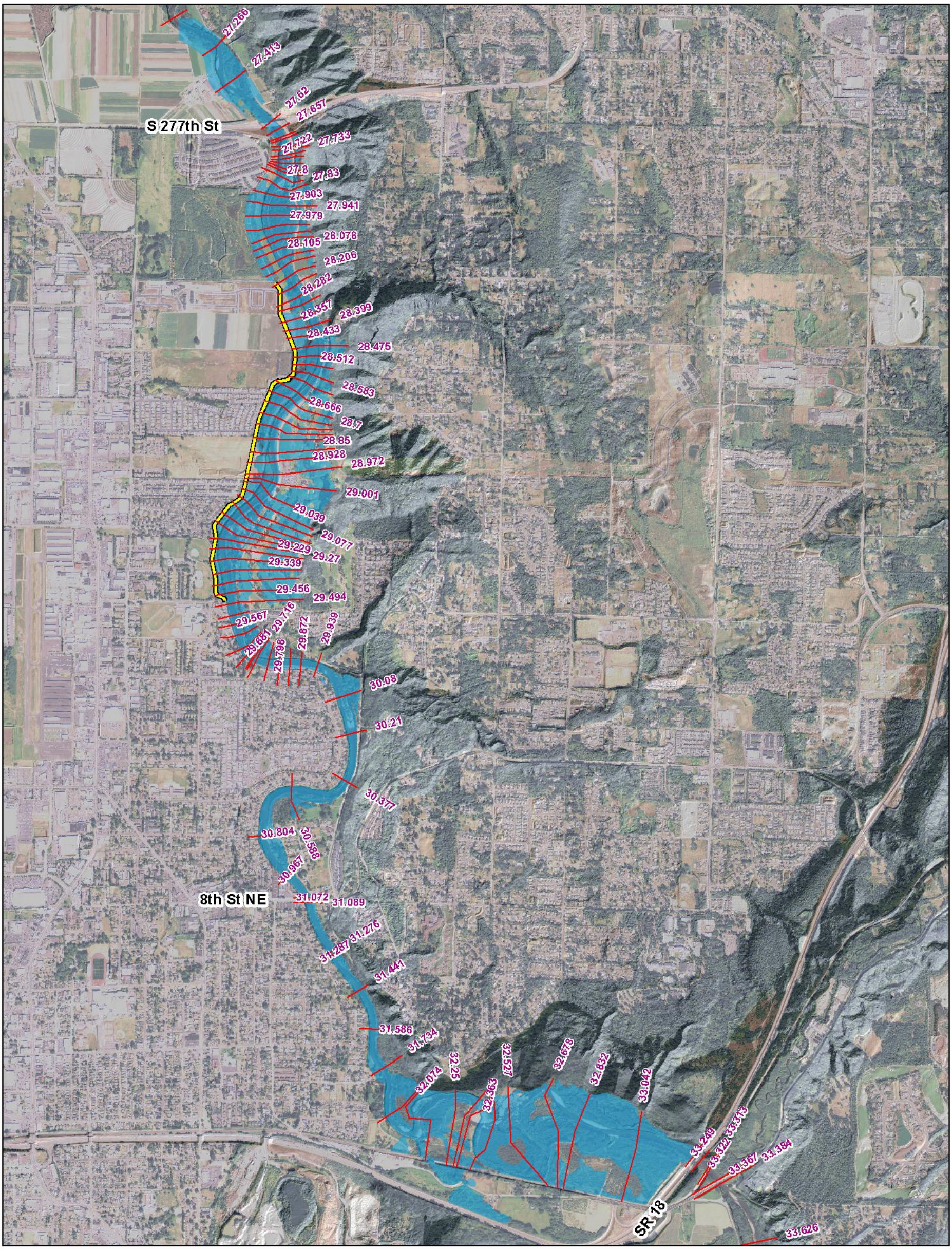


Figure 3: HEC-RAS Model Cross Section Layout